Mapping Health in the Great Lakes Areas of Concern: A User-Friendly Tool for Policy and Decision Makers

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The role of the physical environment as a determinant of health is a major concern reported by the general public as well as by many policymakers. However, it remains one of the health determinants for which few available measures or indicators are readily available. This lack of data is compounded by the fact that evidence for direct cause-and-effect relationships in the literature is often equivocal, leading to feelings of uncertainty among the lay public and often leading to indecision among policymakers. In this article we examine one aspect of the physical environment—water pollution in the Great Lakes Areas of Concern (AOCs)—and its potential impacts on a wide range of (plausible) human health outcomes. Essentially, the International Joint Commission, the international agency that oversees Great Lakes water quality and related issues, worked with Health Canada to produce a report for each of the 17 AOCs on the Canadian side of the Great Lakes, outlining a long list of health outcomes and the potential relationships these might have with environmental exposures known or suspected to exist in the Great Lakes basin. These reports are based solely on secondary health data and a thorough review of the environmental epidemiologic literature. The use of these reports by local health policymakers as well as by public health officials in the AOCs was limited, however, by the presentation of vast amounts of data in a series of tables with various outcome measures. The reports were therefore not used widely by the audience for whom they were intended. In this paper we report the results of an undertaking designed to reduce the data and present them in a more policy-friendly manner, using a geographic information system. We do not attempt to answer directly questions related to cause and effect vis-à-vis the relationships between environment and health in the Great Lakes; rather, this work is a hypothesis-generating exercise that will help sharpen the focus of research into this increasingly important area of public health concern. *Key words:* environment, health, Great Lakes, GIS, policy. — *Environ Health Perspect* 109(suppl 6):817–826 (2001).
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The determinants of health literature that currently guide much of health policy making in Canada (*1*) and beyond (*2,3*) include a broad range of determinants. Within this conceptual framework, health is determined not only on the basis of access to healthcare but also levels of poverty, social support/social capital, as well as the physical environment. The role of the physical environment as a determinant of health is a major concern reported by the general public, as well as many policymakers (*4,5*). However, it remains one of the health determinants for which few measures or indicators are readily available. Furthermore, major population surveys in Canada have been attempting to address the major determinants of the populations' health, and yet clearly articulated indicators of the contribution of the physical environment to human health remain poorly documented, if at all. This is underscored by the recent *Statistical Report on the Health of Canadians* (*6*) wherein the authors admit:

> . . . data on environmental indicators are the oldest in this Report and are an exception to the general rule that 'current' statistics would be no older than 1994-95 . . . the lack of up-to-date, comprehensive and regionally relevant environmental indicators represents a major gap in an otherwise reasonably comprehensive view of the factors affecting Canadians' health.

This lack of data is compounded by the fact that evidence for direct cause-and-effect relationships in the literature is often equivocal, leading to feelings of uncertainty among the lay public and often leading to indecision among policymakers. Many commentators have noted the difficulty of representing clearly and adequately the relationship between environmental exposures and the variety of health outcomes plausibly related to such exposures (*7–9*).

In this article we examine one aspect of the physical environment—water pollution in the Great Lakes Areas of Concern—and its potential impacts on a wide range of (plausible) human health outcomes. Essentially, the International Joint Commission (IJC), the international agency that oversees Great Lakes water quality and related issues, worked with Health Canada to produce a report for each of the Areas of Concern (AOCs) on the Canadian side of the Great Lakes (n =17) outlining a long list of health outcomes and the potential relationships these might have with environmental exposures known or suspected to exist in the Great Lakes basin. No systematically collected exposure data were available to Health Canada when these reports were drafted; therefore, the reports are based solely on secondary health data as well as a thorough review of the environmental epidemiologic literature. Use of these reports by local health policymakers and public health officials in the AOCs was limited by the presentation of vast amounts of data in a series of tables with various outcome measures. The reports were not used widely by the audience for whom they were intended as they were seen as too technical, poorly specified in terms of environment and health relationships, and too wide ranging with little or no commentary on the significance of the many relationships documented. Indeed, given so much data and analyses, it is not surprising that statistically significant relationships were revealed (*10*).

A primary focus of the current undertaking, then, was to reduce the data and present them in a more policy-friendly manner. Thus, we do not attempt in this article to answer directly questions related to cause and effect vis-à-vis the relationships between environment and health in the Great Lakes; rather, this work is a hypothesis-generating exercise that will help sharpen the focus of research into this increasingly important area of public health concern. In so doing, geographic information systems (GIS) are used to map existing health outcome data available from secondary data sources at Health Canada to produce policy-friendly tools for decision making. The methodology used in undertaking the analysis is described in the next section.

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Methodology

A location map of the Canadian AOCs (Figure 1) was created using the census subdivisions (CSDs) included in each AOC. That is, the original boundaries drawn around the AOCs by the IJC were deliberately chosen to match census boundaries to facilitate analyses of secondary data in these areas. The shape of the Collingwood Harbour AOC is an approximation, given the need to aggregate two separate census files due to amalgamation. Also note that Akwesasne and Tyendinaga Mohawk Territory has no population reported in the census. This is reflected in the 1991 total population for their respective AOCs. The 1991 census population was used for subsequent standardization of health outcomes.

Once a location map was developed, it was essential to establish a protocol for determining which of the health status indicators documented in the Health Canada reports occurred in sufficient numbers and/or were plausibly related to an environmental exposure. In so doing, a three-step process was followed. First, the Health Canada data (1986–1992) were screened for any health outcomes that appeared to be occurring in relatively high numbers within any of the AOCs. Second, the environment and health literature was reviewed for plausible relationships between water pollution in general and adverse health outcomes of any type. Third, health outcomes of particular interest not included in the first two steps but relevant to policymakers in the IJC were included in the list of plausible environment and health relationships. For example, recent media attention to the rates of testicular cancers and other reproductive organ outcomes prompted their inclusion in the list of health outcomes to be mapped. Following this essentially three-step process, it was possible to create a relatively parsimonious set of health outcomes (Table 1) for inclusion in the GIS mapping exercise, although many more outcomes were investigated (Table 2) than are reported here or in the final report to the IJC (*11*). Health outcomes were examined by sex, but not by race, given the relative neutrality of this issue in the Canadian context. Health outcomes were of three types: incidence (relating solely to cancer), mortality, and morbidity, measured using hospital separation (i.e., discharge) data. The limitations of the morbidity data must be duly noted; that is, some health outcomes of interest (e.g., spontaneous abortions) do not necessarily require hospitalization and therefore may be affecting the (statistically significant) relationships revealed through the data. Other limitations relate to the relatively arbitrary nature with which the AOC boundaries were established. While the use of existing administrative boundaries is very useful in terms of analysis, they may not accurately reflect exposure patterns of interest.

Maps were produced in ArcView GIS (*12*) using the data provided in the 17 individual AOC reports prepared by Health Canada. All outcomes were plotted by quartile. Significance levels as reported by Health Canada are indicated by the solid colors on the maps; hatched areas indicate nonsignificant differences from the province as a whole. Many but not all of the findings are reported below; not all the maps created are included in this article. Eyles and Elliott (*11*) present a full reporting of the findings as well as maps for each of the health outcomes examined.

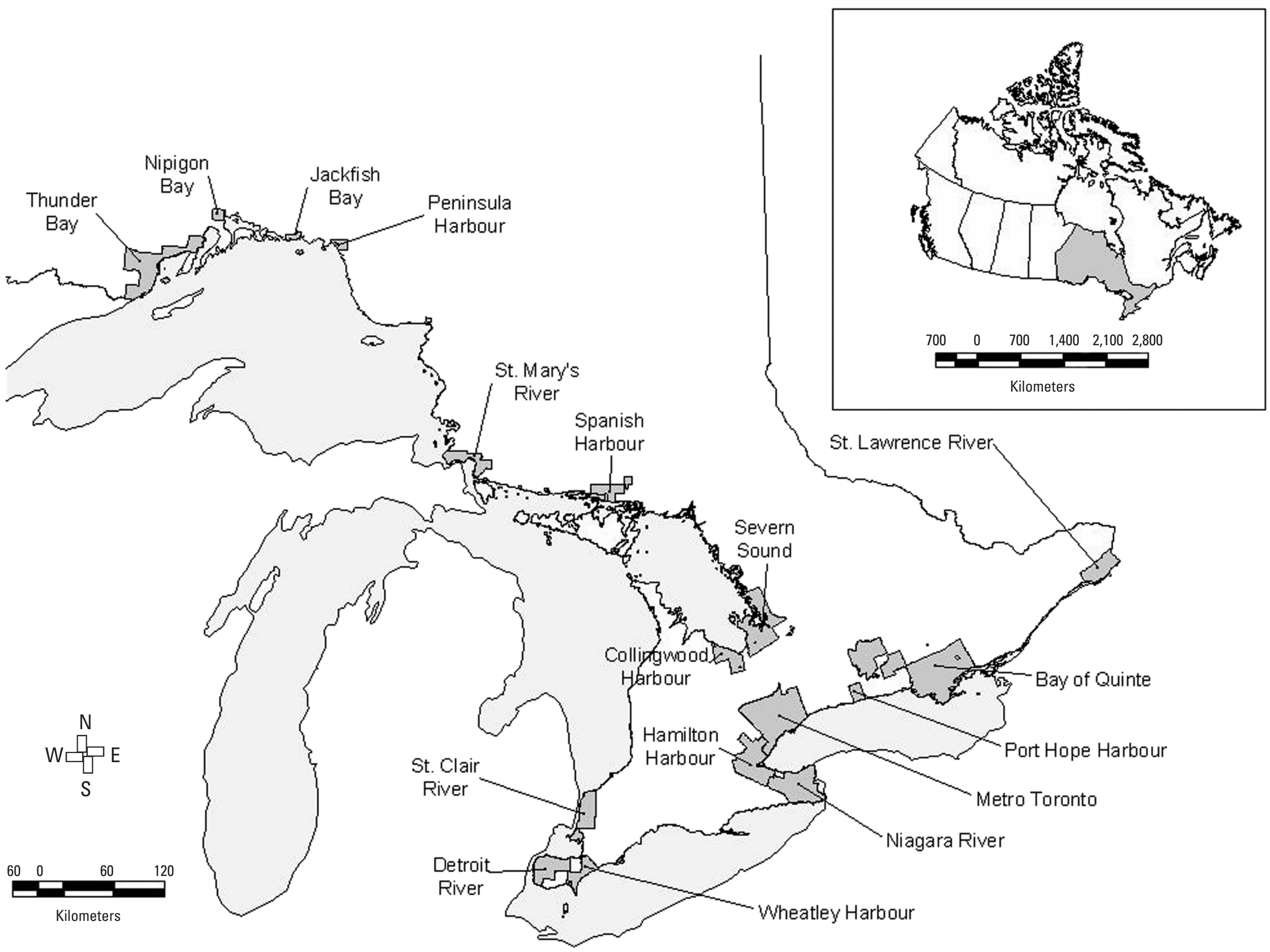

Figure 1. Solid colors indicate statistically significant rates.

Findings

Cancer

Many environmental pollutants have been identified as potential carcinogens, probable carcinogens, and carcinogens. Some are found in drinking water, others bioaccumulate in fish and waterfowl, and others are present in the air. Although it is estimated that only about 5% of cancers are due to environmental factors (*13*), and geophysical properties appear to play a greater role than human-made pollutants (*13*), some studies reveal an increasing frequency of cancer in polluted areas (*14*). However, much of the data relating environmental pollutants to cancer come from occupational studies [for a review, see Eyles and Elliott (*11*)].

An analysis of cancer incidence across the 17 AOCs on the Canadian side of the Great Lakes indicated no statistically significant standardized incidence ratios (SIRs) for all cause cancer in females, with only one AOC (the Detroit River) showing a statistically significant SIR relative to the rest of the province for males. Incidence of specific cancers showed only cancer of the liver and intrahepatic bile ducts in two of the AOCs (Metro Toronto and St. Lawrence), with women in these areas being up to 2 times more likely to develop these cancers than women in other parts of the province. Incidence of cancer of the colon and rectum for males (Figure 2) indicates statistically significantly high SIRs in two other AOCs (Thunder Bay and St. Clair River), whereas incidence of cancer in liver and intrahepatic bile ducts (Figure 3) indicates Metropolitan Toronto and the St. Clair River AOCs as areas of statistically significantly high SIRs for this cancer outcome. Only one AOC reveals a statistically significant SIR for testicular cancer; males in Wheatley Harbour are 2.5 times more likely to develop testicular cancer than males in other parts of the province.

With respect to cancer mortality, for females, no statistically significant standardized mortality ratios (SMRs) are found for breast cancer, while women in 2 of the 17 AOCs (Thunder Bay and Detroit River) are at higher risk for death from pancreatic cancer (Figure 4). Again, the Detroit River AOC is found to have a statistically significant SMR for pancreatic cancer for males.

Diseases of the Reproductive Organs

Disorders of the female genital tract include endometriosis; genital prolapse; fistulae involving the female genital tract; noninflammatory disorders of the ovary, fallopian tube, and broad ligament; disorders of the uterus not classified elsewhere; noninflammatory disorders of the cervix, vagina, vulva, and peritoneum; pain and other symptoms associated with the female genital organs; disorders of menstruation and other abnormal bleeding from the female genital tract; menopausal and postmenopausal disorders; infertility; and other disorders of female genital organs (*15*). This classification of disease for males includes hyperplasia of the prostate, inflammatory disease of the prostate, other disorders of the prostate, hydrocele, orchitis and epididymitis, redundant prepuce and phimosis, infertility, disorders of the penis, and other disorders of the male genital organs (*15*).

The pattern seen in Figure 5 indicates first a relatively wide range in the SMR for morbidity of the female genital tract for all ages (from 0.84 to 2.24) with 8 of 17 AOCs (Thunder Bay, Nipigon Bay, Jackfish Bay, Peninsula Harbour, St. Mary's River, Spanish Harbour, Severn Sound, and St. Clair River) characterized by both high and statistically significant SMRs. When broken down by age group, we see a slightly different pattern emerging, influenced by the relatively high rates among younger women. For example, SMRs for the 0–24-year age group exhibit a similar pattern (with the highest rates typically in the northern AOCs), the range of SMRs is greater (from 0.76 to 3.33), indicating that, for example, the likelihood

Table 1. Health outcomes assessed in Great Lakes AOCs.

Mortality, cancer, all causes, females
Mortality, pancreatic cancer, females
Mortality, breast cancer, females
Mortality, cancer, all causes, males
Cancer of liver and intrahepatic bile ducts, males
Mortality, pancreatic cancer, males
Cancer incidence, all causes, females
Cancer incidence, liver and intrahepatic bile ducts, females
Cancer incidence, all causes, males
Cancer incidence, colon and rectum, males
Cancer incidence, liver and intrahepatic bile ducts, males
Cancer incidence, testicular
Morbidity, female genital tract
Morbidity, female genital tract, ages 0–24 years
Morbidity, endometriosis
Morbidity, endometriosis, ages 0–24 years
Morbidity, spontaneous abortion
Morbidity, diseases of the male genital organs
Morbidity, diseases of the male genital organs, ages 0–24 years
Mortality, testicular cancer
Mortality, COPD and allied conditions, females
Morbidity, COPD and allied conditions, females
Mortality, COPD and allied conditions, males
Morbidity, COPD and allied conditions, males
Morbidity, asthma, females
Morbidity, asthma, males
Congenital anomalies, males
Congenital anomalies, females
Morbidity, diabetes mellitus, females
Morbidity, diabetes mellitus, females, ages 45–74 years
Morbidity, diabetes mellitus, males
Morbidity, diabetes mellitus, males, ages 45–74 years
Morbidity, intestinal infectious diseases, females
Morbidity, intestinal infectious diseases, males
Morbidity, disorders of thyroid, females

Table 2. Additional health outcomes investigated.

Mortality, all causes, males
Mortality, all causes, females
Mortality, cancer of colon and rectum, males
Mortality, cancer of colon and rectum, females
Mortality, cancer of liver and intrahepatic bile ducts, females
Morbidity, disorders of the thyroid, males
Morbidity, infertility, females
Cancer incidence, colon and rectum, females
Cancer incidence, breast, females,
Birth weights, males
birth weights, females
Mortality, diabetes mellitus, males
Cancer incidence, pancreas, males
Mortality, diabetes mellitus, females
Cancer incidence, pancreas, females
Morbidity, endometriosis, ages 25–44 years
Morbidity, endometriosis, ages 45–74 years
Morbidity, female genital tract, ages 25–44 years
Morbidity, female genital tract, ages 45–74 years
Morbidity, female genital tract, ages ≥75 years
Morbidity, diabetes mellitus, females, ages 0–24 years
Morbidity, diabetes mellitus, females, ages 25–44 years
Morbidity, diabetes mellitus, females, ages ≥75 years
Morbidity, diseases of the male genital organs, ages 25–44 years
Morbidity, diseases of the male genital organs, ages 45–74 years
Morbidity, diseases of the male genital organs, ages ≥75 years
Morbidity, diabetes mellitus, males, ages 0–24 years
Morbidity, diabetes mellitus, males, ages 25–44 years
Morbidity, diabetes mellitus, males, ≥75 years
Morbidity, disorders of thyroid, females, ages 0–24 years
Morbidity, disorders of thyroid, females, ages 25–44 years
Morbidity, disorders of thyroid, females, ages 45–74 years
Morbidity, disorders of thyroid, females, ages ≥75 years

of being hospitalized for a disorder of the female genital tract is over 3 times greater for young women in Nipigon Bay than in the rest of the province.

Standardized morbidity ratios for endometriosis for all ages ranged from 0.48 to 2.33 (Figure 6), with five AOCs having relatively high and statistically significant SMRs (Thunder Bay, Peninsula Harbour, St. Lawrence River, St. Clair River, and Niagara River). Again, however, when we look particularly at young women (0–24 years), the range in SMRs is far greater (from 0.26 to 4.40), indicating that a young woman in Thunder Bay is over 4 times more likely to be hospitalized for endometriosis than those elsewhere in the province. No AOCs reported statistically significantly high rates of mortality or morbidity for spontaneous abortions.

Standardized morbidity ratios for male reproductive organs (all ages) were lower than for females, with a range of 0.75–1.47. Four of the 17 AOCs were found to have relatively high and statistically significant SMRs (Peninsula Harbour, St. Clair River, Niagara River and Detroit River). The range in SMRs for male reproductive organs (Figure 7) is much greater (0.60–3.25) when the focus is on young men (0–24 years). Indeed also, the number of AOCs with SMRs that could be considered high and statistically significant also expands to 6 (Thunder Bay, Jackfish Bay, St. Mary's River, Spanish Harbour, Niagara River, and Detroit River). None of the 17 AOCs displayed statistically significantly high SMRs for testicular cancer.

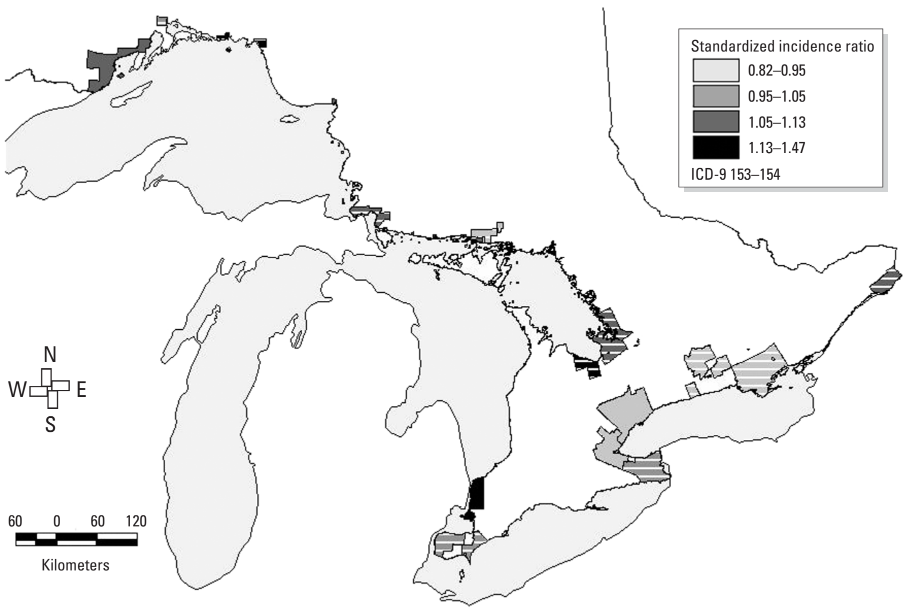

Figure 2. Solid colors indicate statistically significant rates.

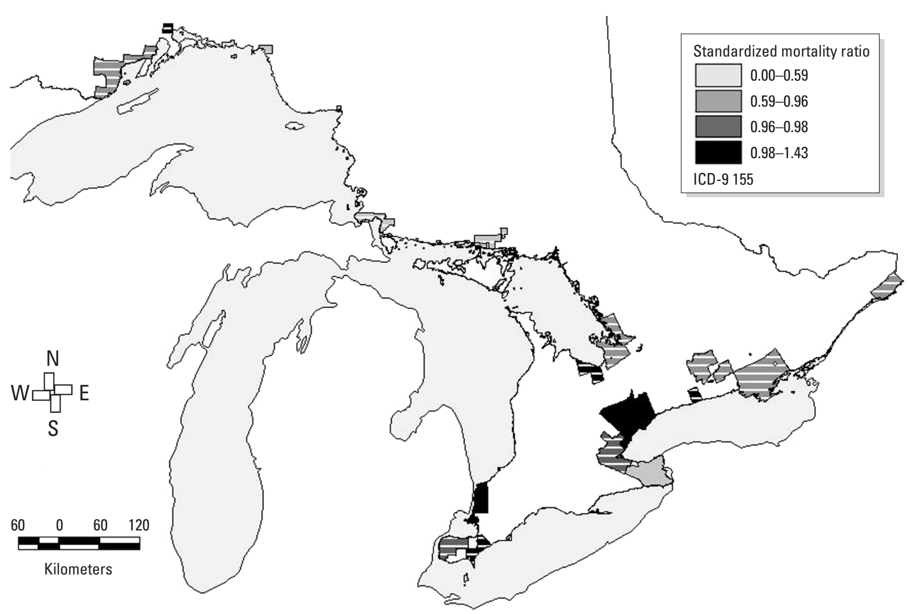

Figure 3. Solid colors indicate statistically significant rates.

Chronic Obstructive Pulmonary Disorders

This category includes bronchitis, emphysema, asthma, bronchiectasis, extrinsic allergic alveolitis, and chronic airway obstruction not classified elsewhere (*15*). Standardized mortality ratios for chronic obstructive pulmonary disorders (COPDs) indicate that females in only 2 of the 17 AOCs (Bay of Quinte and St. Lawrence River) are more likely to die of this and related disorders than females in other parts of the province. Morbidity from these disorders is more likely to affect females in 8 of the 17 AOCs (Nipigon Bay, Peninsula Harbour, St. Mary's River, Spanish Harbour, Severn Sound, Detroit River, St. Clair River, and St. Lawrence River).

Standardized mortality ratios for COPDs indicate that males in 3 of the 17 AOCs (Severn Sound, Bay of Quinte, and St. Lawrence River) are more likely to die of this and related disorders than males in other parts of the province. Morbidity from these disorders is more likely to affect males in 7 of the AOCs (Nipigon Bay, Peninsula Harbour, St. Mary's River, Spanish Harbour, St. Clair River, St. Lawrence River, and Collingwood Harbour).

Asthma is a particular respiratory health concern in terms of environmental exposures (*16*). Both males and females in 4 of the AOCs (Peninsula Harbour, St. Mary's River, Port Hope Harbour, and St. Lawrence River) are between 1.27 and 2.98 times more likely to develop asthma than their counterparts in other parts of the province (see, e.g., Figure 8).

Congenital Anomalies

Both boy and girl babies are more likely to experience congenital anomolies in the Thunder Bay AOC; boys are likely to experience this health outcome in Peninsula Harbour and the Bay of Quinte; girl babies are only likely to experience congenital anomolies when born in Nipigon Bay.

Diabetes

Statistically significantly high rates of morbidity for diabetes mellitus in females (Figure 9) were found in 8 of the 17 AOCs [St. Mary's River, Severn Sound, St. Clair River, Detroit River (SMRs of between 1.19 and 1.41) and Nipigon Bay, Jackfish Bay, Peninsula Harbour, Spanish Harbour (with SMRs between 1.41 and 3.76)]. Statistically significantly high rates of morbidity for males were found in 7 of the AOCs (Nipigon Bay, Jackfish Bay, Peninsula Harbour, and Spanish

Harbour residents are between 1.44 and 3.45 times more likely to be hospitalized for diabetes mellitus; males in Severn Sound, Detroit River, and St. Clair River are between 1.14 and 1.44 times more likely).

Intestinal Infectious Diseases: Morbidity

Intestinal infectious diseases include cholera; typhoid and paratyphoid fever; salmonellosis; shigellosis and other bacterial food poisoning; amoebiasis and other protozoal intestinal diseases such as protozoal colitis, diarrhea, dysentery, giardiasis, and infection colitis; enteritis; and gastroenteritis, as well as intestinal infections due to other organisms and ill-defined intestinal infections (*15*). Women in Peninsula Harbour, Spanish Harbour, Bay of Quinte, and Port Hope are between 1.20 and 6.15 times more likely to be hospitalized for intestinal infectious diseases than women in other parts of the province. Indeed, women in Peninsula Harbour are over six times more likely to be hospitalized for this disorder. Relatively high (1.18–6.38) and statistically significant SMRs for intestinal infectious diseases in males (Figure 10) can be found in the Peninsula Harbour, Spanish Harbour, and Port Hope AOCs, with males in Peninsula Harbour being over 6 times more likely to be hospitalized from this disorder than males in other parts of the province. Slightly lower (1.00–1.18) but still statistically significant SMRs can be found in the Bay of Quinte, Niagara River, and Detroit River AOCs.

Thyroid, Morbidity in Females

Disorders of the thyroid gland include goiter, hypothyroidism, thyroiditis, and others. Women living in the St. Clair River, Jackfish Bay, and Collingwood Harbour AOCs are between 1.37 and 4.16 times more likely to be hospitalized for disorders related to thyroid than women living in other parts of the province. While SMRs in the St. Mary's and Detroit River AOCs were also statistically significant, they were slightly lower (between 1.16 and 1.37).

Discussion

The previous section provides a partial inventory of health outcomes experienced in the Great Lakes AOCs on the Canadian side of the border that could plausibly be related to environmental exposures, primarily water pollution but perhaps also some air pollution. We now make the links to the literature around these plausible environment and health relationships to explore further some of these associations. We then present the data in a slightly different form so that we may look at the collective of communities affected and speculate on some policy implications of the work, demonstrating its importance for hypothesis generation at the community level.

Cancer

We now know that certain types of cancers are plausibly related to environmental exposures. In the context of the health outcomes in the Great Lakes, some studies have shown a significantly higher incidence of pancreatic cancer following exposure to radiation from nuclear fallout (*17*) or as a result of therapy for ankylosing spondylitis (*18*). Occupational exposure to pesticides, solvents, petroleum compounds, and naphthylamine has been associated with pancreatic cancer in chemical and coke plant workers, sawmill workers, paper manufacturers, miners and metal workers, and those in medical trades (*18–20*).

Infection, specifically with the hepatitis B virus and the hepatitis C virus, has been identified as the most important etiologic factor in liver cancer (*18*). Other factors such as diseases, for example, cirrhosis (*21*), hemochromatosis, and diabetes, and the ingestion of estrogen, oral contraceptives, and androgens, have also been associated with this cancer (*18*). Studies have also shown an association between liver cancer and cigarette smoking (*22,23*), and alcohol consumption (*22,24*). Chemical carcinogens such as aflatoxins may be involved in the disease (*25*). Laboratory studies have found that liver cancer increases following exposure to pesticides, herbicides, pyrralizidine alkaloids,

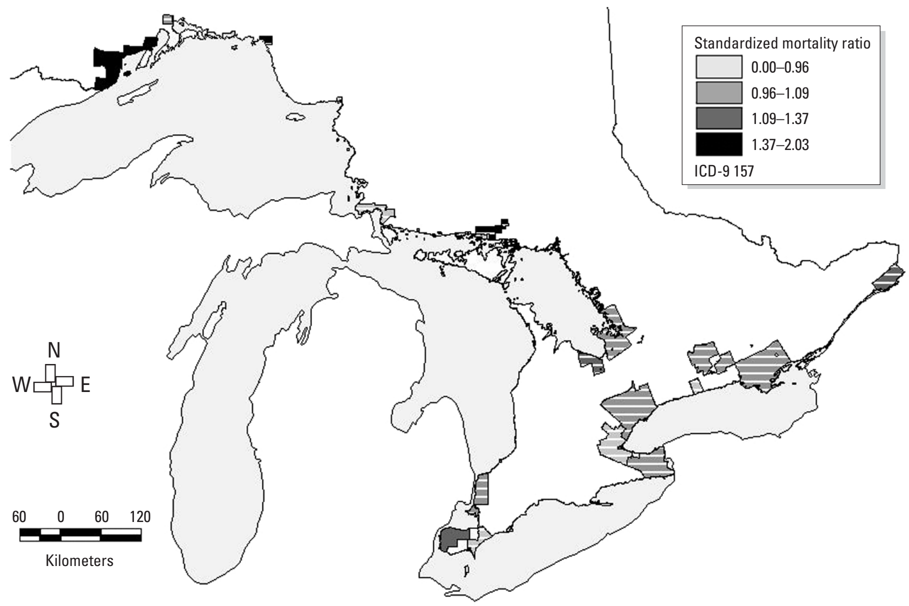

Figure 4. Solid colors indicate statistically significant rates.

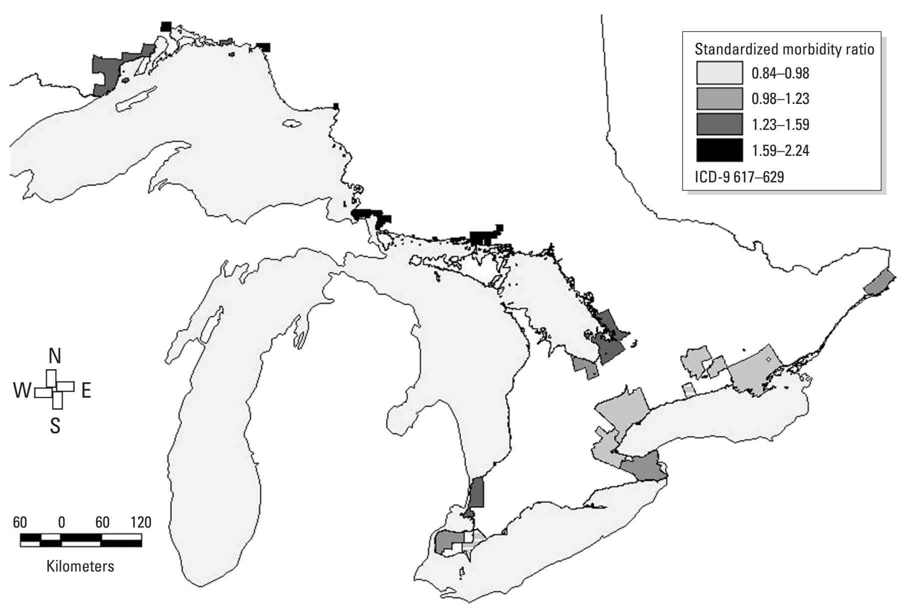

Figure 5. Solid colors indicate statistically significant rates.

and industrial chemicals, specifically cycasin and nitrosamines (*18,25,26*).

Economic and social risk factors are implicated in colorectal cancer, since the highest incidence of this cancer are, with the exception of Japan, in the most industrialized countries (*17*). Genetic and anatomic factors play a role and being male, subsisting on a Western diet (*27,28*), consuming alcohol (*29*) and tobacco (*30*), migrating to high-risk countries, possessing a higher income and education, and consuming highly refined foods, sugar, and caffeine along with nulliparity and previous diseases of the bowel (*31*) all increase colorectal cancer risk (*18*). Some studies have found that exposure to radiation can result in a significantly higher risk of colon and rectal cancer (*17*) and that long-term consumption of chlorinated surface water (*32*) can increase the risk of colon cancer (*17*).

Although the risk factors associated with testicular cancer are not well known, the cancer has been associated with undescended testes, persistent cryptorchidism, postpubertal orchiopexy subfertile men, and atrophic testes (*33*). The effects of environmental contaminants, specifically those with estrogenic properties, on the development and function of reproductive organs are not yet known.

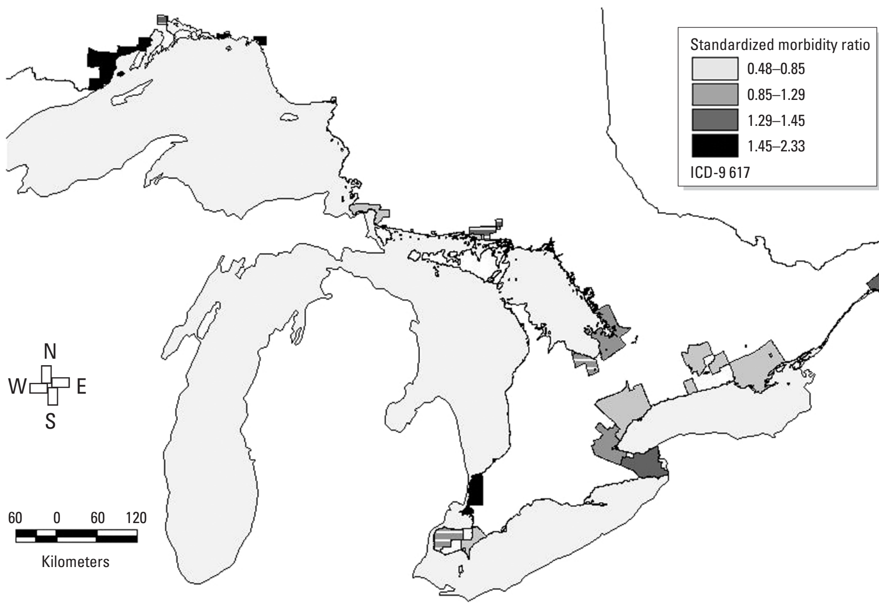

Figure 6. Solid colors indicate statistically significant rates.

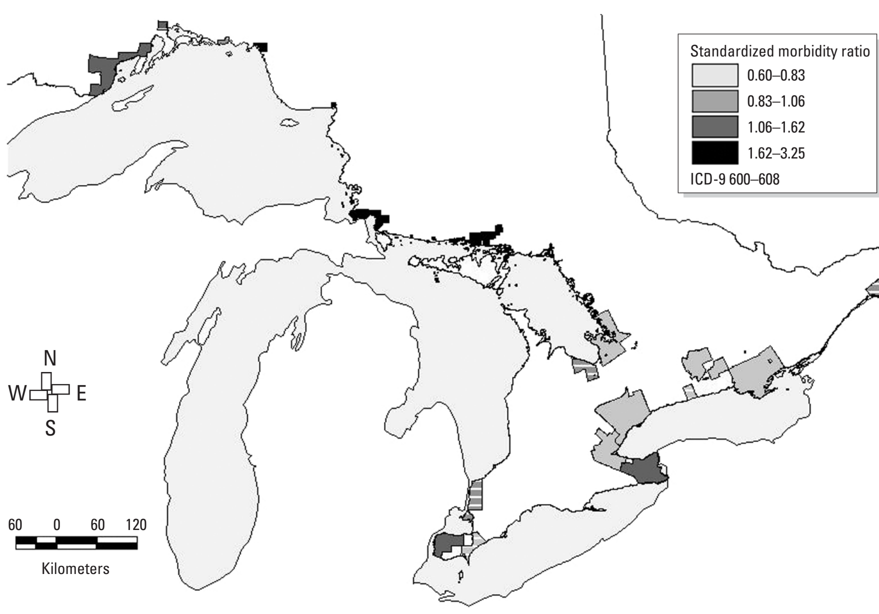

Figure 7. Solid colors indicate statistically significant rates.

Diseases of the Reproductive Organs

Although endometriosis is very common in women of reproductive age and may be a genetic condition (*34*), its etiology remains unclear. It has also been associated with müllerian anomalies and uterine outflow obstruction (*34*), and in animal studies with organochlorines (*35*).

Female genital tract disorders can be hereditary or caused by several factors including herniation, delivery, a significant alteration in pelvic support, injury, complications of surgery, and abnormal release of anterior pituitary gonadotropins, intracystic hamorrhage, hypothroidism, sexual precocity, *in utero* exposure to diethylstilbestrol, habitual abortion, and congenital anomalies (*34*). Hexacholorobenzene, found in Great Lakes waters, may be associated with damage to the structure of the ovary (*34*) and pesticides have been linked with reproductive failure in animals (*36*) and humans (*37–39*).

With respect to male genital tract disorders, prostatitis can be caused by coliform bacteria such as *Escherichia coli,* pseudomonas, enterococci and staphylococci, and in some cases by vasculitis (*40,41*); hydrocele can result from local injury, radiotherapy, epididymitis, and orchitis (*41*); orchitis can be a consequence of mumps, tuberculosis, syphilis, and autoimmune diseases (*41*); and epididymitis, caused by enterobacteriaceae and pseudomonas, can result from trauma, reflux of sterile urine, and sexual activity (*41*). Phimosis is a chronic infection due to poor local hygiene (*41*). Disorders of the penis, when not idiopathic, can be associated with leukemia, sickle cell disease, pelvic intracavernous injection therapy for impotence, severe vasculitis, and chronic inflammation (*41*). Pesticides have been linked to reproductive failure in animals (*36*) and infertility in humans (*37,39*).

COPD and Asthma

Although the main risk factor for these diseases is cigarette smoking (*42,43*), air pollution, specifically high concentrations of particulate matter and sulfur dioxide, clearly can also be a cause of illness and death from them (*36,43,44*). However, the full impact of existing pollution levels is unclear (*36*) and other factors such as heredity, socioeconomic level, race, sex, body weight, occupational risks, allergies, and bronchial hyperactivity may play a role in the development of these diseases (*36,45,46*).

Congenital Anomalies

These can result from advanced maternal age (*47*), mutant genes, chromosome abnormalities, infectious diseases, therapeutic drugs, radiation and environmental contaminants (*48*), and accidental and occupational exposure to high levels of chemical contaminants (*49–52*). Teratogens can produce congenitally malformed variants as well as spontaneous abortions (*36*); certain chemicals are embryopathic and are suspected of affecting human prenatal development (*36*); heavy metals and organochlorine compounds can result in fetal malformations (*53,54*).

Diabetes

Several factors may be involved in Type 1 diabetes mellitus. The condition can be hereditary or immune mediated (*55,56*). Furthermore, it can be related to viruses such as mumps, rubella, cytomegalovirus, Coxsackie viruses, retroviruses, and reoviruses (*55*), linked to encephalomyocarditis, or a result of exposure to betacytotoxin chemicals such as nitroso compounds and Vacor. Dioxins and furans have been associated with an increased risk of diabetes in males (*57,58*).

Intestinal Infectious Diseases

Some of these diseases can result from exposure to contaminated drinking or recreational water (*15,36,59–61*). Although microbiologic data from the Great Lakes Basin are scarce (*58*), organisms causing intestinal infections have been detected in various bodies of fresh water. Pathogenic bacteria, viruses, and protozoa that could possibly be found in the Great Lakes Basin are listed and described below.

Aeromonas hydrophila cause acute diarrhea (*59,62*) and gastroenteritis (*61*), and the bacteria are found in surface waters and sewage; *Campylobactre jejuni* cause acute gastroenteritis in humans (*59*). Found in poultry, cattle, sheep, pigs, and dogs (*59,62*), the bacteria could contaminate water through agricultural runoff. Certain species of the genus Clostridium can cause intestinal infections, and may be found in water as a result of contamination through sewage or runoff (*59,62*). Escherichiae, mostly *E. coli*, can cause diarrhea and gastroenteritis in humans (*59,61,62*) and are widely distributed in nature. Salmonella are usually associated with food poisoning (*61,62*), but certain species of the bacterium can cause enteric and typhoid fever in humans (*59,61,62*). The bacteria are found in contaminated water. The *Shigella* genus can contaminate water through sewage, and the bacteria can cause dysentery, diarrhea, and gastroenteritis in humans (*59,61,62*). The genus *Yersinia* can cause intestinal infections, and the bacteria have been found in contaminated water as a result of sewage disposal and runoff (*59,62*).

Viruses such as echovirus (or rhinovirus Type 1) (*59*), Norwalk virus, rotavirus, and adenovirus can contaminate freshwaters and can cause intestinal infections (*62*). Certain protozoans such as cryptosporidium (a livestock parasite), *Giardia lamblia* (a parasite of beavers, muskrats, and deer), and *Entameba histolytic* can be found in freshwater and result in intestinal infections such as gastroenteritis or dysentery in humans (*61,62*).

Thyroid

Although goiter can be hereditary, it can also result from an iodine deficiency, an iodine excess, thyrotoxicosis, or exposure to environmental toxins (*55,63*). Hypothyroidism can develop after an acquired thyroid disease or after treatment of such a disease (surgery, drugs, or radioactive iodine or external radiation treatment). It can also be hereditary or a result of congenital abnormalities, hypothalamic–pituitary disease, or thyroiditis (*55*). Both cadmium (*54*) and iodine (*63*) can have effects on thyroid function, and radiation, lead, and halogenated aromatics such as hexachlorobenzene, polybrominated biphenyls, polychlorinated biphenyls, and dioxins have been associated with thyroid dysfunction (*55,64,65*). In addition, evidence that organochlorines can affect the thyroid gland has been found in animal studies (*65,66*).

Conclusions

There is some evidence from the literature that the health outcomes documented in the Great Lakes AOCs on the Canadian

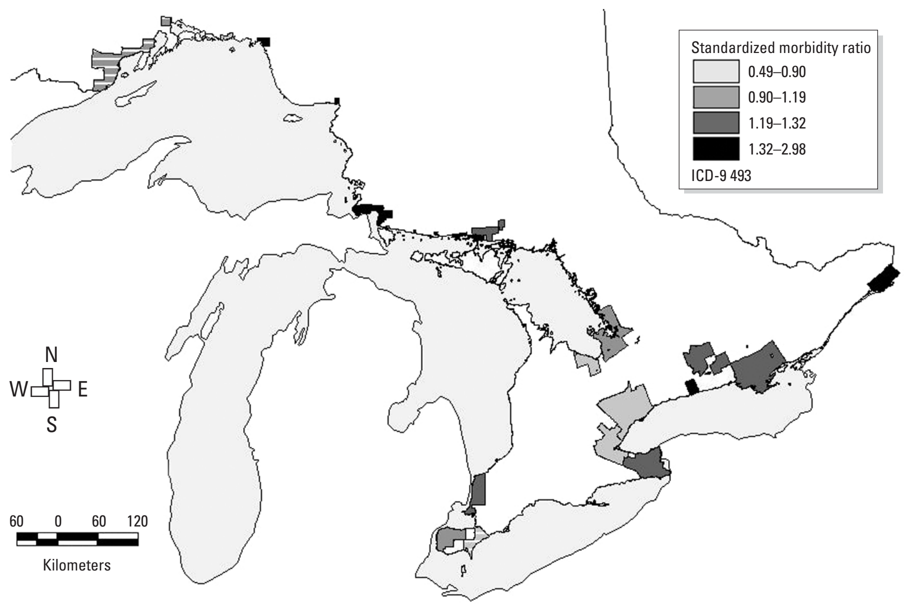

Figure 8. Solid colors indicate statistically significant rates.

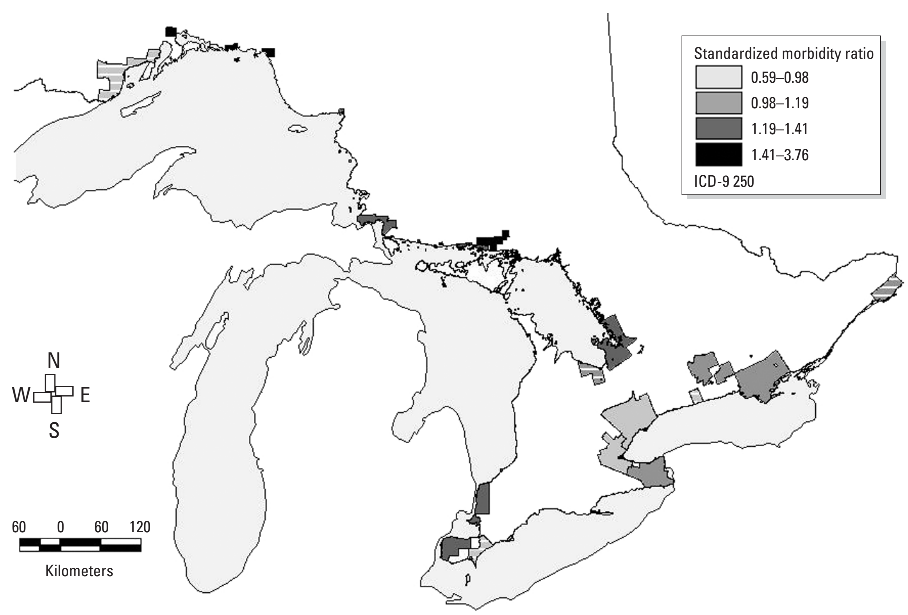

Figure 9. Solid colors indicate statistically significant rates.

side of the border are plausibly related to environmental exposures. The complex picture of environment and health relationships reported here in some respects presents a scientific maze for policymakers; that is, there is so much that is (potentially) significant that it may be difficult to know where to concentrate finite and limited resources. While we assert that mapping the Health Canada data provides a useful and policy-friendly lens on the issues, there remain methodologic issues connected with the critical data and well documented as a series of caveats in the Health Canada reports themselves. These include, but are not limited to, the appropriateness of using hospital separations as a surrogate for morbidity; the influence of migration on the validity of using mortality data as a surrogate measure for "exposure"; the well-known limitations on the validity of mortality data; and so on. Furthermore, while the rates are usually standardized to the provincial population, this may not be the best comparator for a binational body like the IJC. It is of central importance to Ontario-based policymakers in public health and environmental regulation. And while the identification of statistical significance is important, such an approach may indicate issues of low incidence or even low public health relevance, given current knowledge and competing public health priorities.

Tables 3 and 4 present the information of the maps and tables in a different way. They identify patterns in the AOCs on the basis of statistical significance of outcomes and those where the standardized rates are above 1, based on the argument that any "above average" deviation from the province is worthy of note. The tables indicate, across the rows, for females, the importance of asthma, COPD, genital tract disorders, and diabetes, whereas for males the outcomes of importance appear to be COPD, asthma, and diabetes. While the relationships between environment (especially air quality) and respiratory disorders is becoming understood and has been taken up by provincial (and federal) policymakers and health regulators, that of relationships between environment and genital tract disorders for women remains a vital area for additional research. It is also possible to conclude that we know more about male reproductive disorders than those of the female as they relate to the environment. The tables also identify the worst areas in terms of number of outcomes. They isolate, for example, for both men and women, the Detroit River and the Niagara River (women only) as worthy of further investigation, even at the ecologic level. Thus, it may be worth analyzing census data to see the associations between some health determinants and the identified health outcomes. In this way, it will be possible to account for, at the ecologic level, some of the nonenvironmental determinants of health. This work is currently being undertaken as part of a larger research program to compare

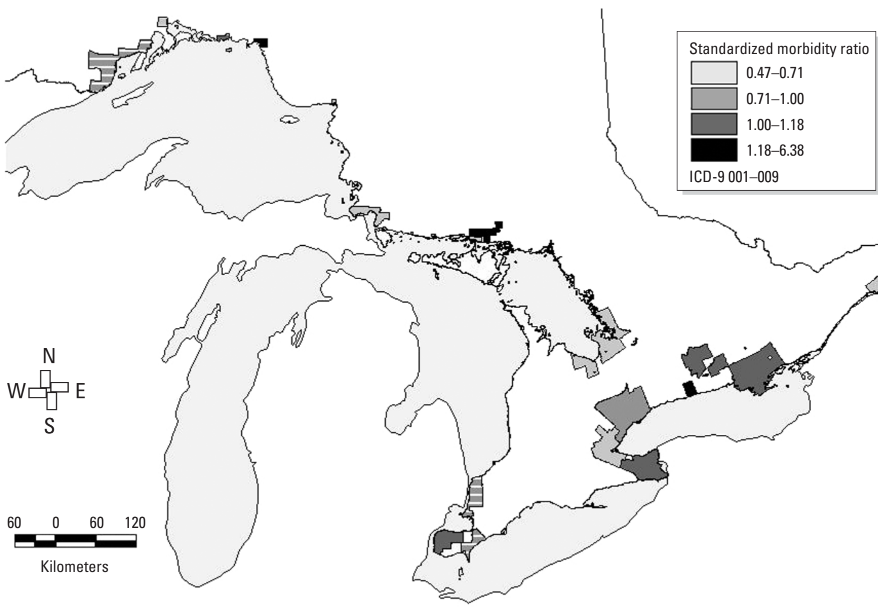

Figure 10. Solid colors indicate statistically significant rates.

Table 3. Summary table of statistically significant SMRs/SIRs >1.00, males, 1986–1992.

	AOC																
Disease	Thunder Bay	Nipigon Bay	Jackfish Bay	Peninsula Harbour	St. Mary's River	Spanish Harbour	Severn Sound	Collingwood Harbour	St. Clair River	Detroit River	Wheatley Harbour	Niagara River	Hamilton Harbour	Metro Toronto	Port Hope	Bay of Quinte	St. Lawrence River
All causes of cancer, incidence										X							
Pancreatic cancer, mortality										X							
Liver cancer, mortality														X			
Colon and rectal cancer, incidence	X								X								
Liver cancer, incidence									X					X			
Testicular cancer, incidence											X						
Male genital organs, morbidity				X	X				X	X		X					
Male genital organs, morbidity (ages 0–24 years)	X		X		X	X				X		X					
COPD, mortality							X									X	X
COPD, morbidity		X		X	X	X		X	X	X		X				X	X
Asthma, morbidity				X	X			X	X			X			X	X	X
Congenital anomalies	X			X						X				X		X	
Diabetes mellitus, morbidity		X	X	X		X	X		X	X		X				X	
Diabetes mellitus, morbidity (ages 45–74 years)		X	X	X		X	X		X	X					X	X	
Intestinal infectious diseases, morbidity				X		X				X		X			X	X	

Table 4. Summary table of statistically significant SMRs/SIRs >1.00, females, 1986–1992.

	AOC																
Disease	*Thunder Bay*	*Nipigon Bay*	*Jackfish Bay*	*Peninsula Harbour*	*St. Mary's River*	*Spanish Harbour*	*Severn Sound*	*Collingwood Harbour*	*St. Clair River*	*Detroit River*	*Wheatley Harbour*	*Niagara River*	*Hamilton Harbour*	*Metro Toronto*	*Port Hope*	*Bay of Quinte*	*St. Lawrence River*
Pancreatic cancer, mortality	X									X							
Liver cancer, incidence														X			X
Genital tract, morbidity	X	X	X	X	X	X	X	X	X	X		X					X
Genital tract, morbidity (ages 0–24 years)	X	X			X	X				X		X					X
Endometriosis, morbidity	X			X			X		X			X					X
Endometriosis, morbidity (ages 0–24 years)	X																
Spontaneous abortions						X					X	X		X			X
COPD, mortality																X	X
COPD, morbidity		X		X	X	X	X		X	X		X			X	X	X
Asthma, morbidity				X	X	X	X		X	X		X			X	X	X
Congenital anomalies	X	X								X				X		X	
Diabetes mellitus, morbidity		X	X	X	X	X	X		X	X		X				X	
Diabetes mellitus, morbidity (ages 45–74 years)		X	X	X	X	X	X	X	X	X		X					X
Intestinal infectious diseases, morbidity				X		X						X			X	X	
Thyroid, morbidity			X		X			X	X	X				X			

AOCs in Canada and the United States for health outcomes of interest and to attempt to explain the patterns observed in a GIS. It is also examining, within Canada, some of the communities that at first seem similar but have very different patterns in the outcome data. For example, the Detroit River (Windsor) and Hamilton Harbour are both located in industrial cities but display remarkably different patterns of morbidity and mortality (*67*). Others show very different patterns for men and women (e.g., Thunder Bay and St. Lawrence River) usually with more elevated outcomes for women potentially explainable in terms of differing occupational exposures but worthy of further investigation. The data present a mass of relationships for consideration for further exploration and analysis. And yet good quality, systematic, and comprehensive exposure data are essential to documenting these relationships more fully even in the suggested exploratory studies. But we assert that, taken together, these ideas and recommendation for further work will enable a discussion of potential explanations of the associations between different health outcomes and environmental factors operating in the Canadian Great Lakes AOCs. Indeed, policymakers have a sharper focus because of the Health Canada data and the results of our mapping exercise. In some cases, our findings reinforce the need for further work (e.g., reproductive outcomes, environment). In others, they demand attention be given to differences in the province. And they indicate the potential of the physical environment as a significant health determinant at the ecologic and community levels.

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